Detect the Fitzgerald-Lorentz Effect

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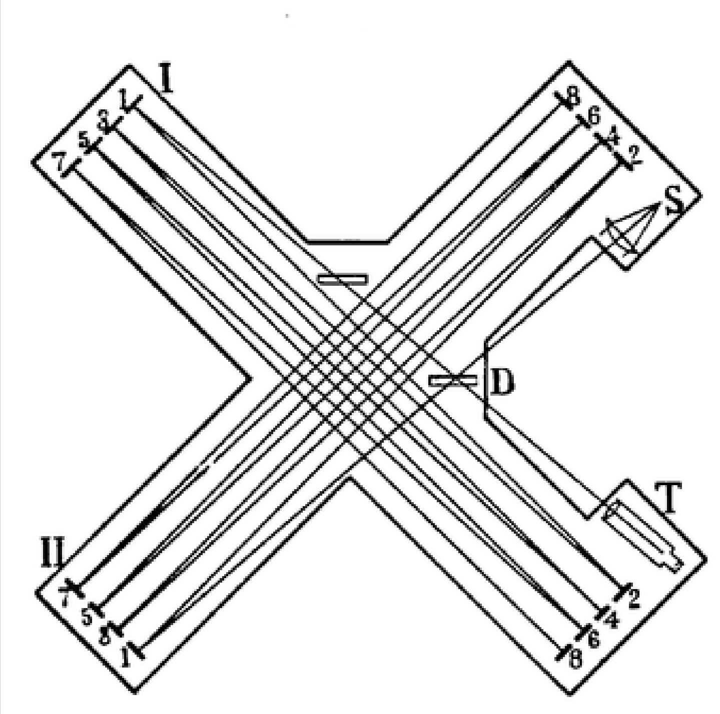
A NULL result was obtained in 1887,[1] in an experiment to detect, if possible, a difference of velocity of light in different directions owing to the motion of the apparatus towards or away from waves of light in the stationary ether. FitzGerald and Lorentz then suggested that the dimensions of the apparatus might be modified by its motion through the ether. If this modification depend on the resilience or other physical properties of the materials, it may perhaps be detected by experiment.

We have constructed two apparatus with which to examine this question. In the first, we replaced the sandstone used in 1887 by a structure of white pine. A strong cross was built up of planks, fourteen inches wide and two inches thick, and fourteen feet long. One was laid east and west, then one across it north and south, and so on. They were slightly notched where they crossed. On their intersection was secured a cast-iron bedplate for certain optical parts of the apparatus. At the ends, after filling the spaces between the planks, were bolted iron supports for our mirrors. The whole was placed on a round float, which in turn rested in a basin of mercury.

Our sixteen mirrors were each four inches in diameter. The mirrors rested each on the points of three adjusting screws, against which they were held by springs. On the bedplate at the intersection of the arms of the cross were placed a plane half-silvered mirror and a compensating plate; these had been, as is usual, cut from the same plane-parallel disk.

Figure 1 is a diagram, not to scale, of the optical arrangements. Light from a source S reaches the mirror D. Part is transmitted, reaching the mirror II. It is successively reflected to 2, 3, 4, 5, 6, 7, and 8. From 8 it returns by the same path to D, where part is reflected to the observer at T. Another part of the incident ray is reflected along the other arm of the cross, is similarly passed to and fro, returned, and at last transmitted to the observer. In the apparatus actually used, mirror 5 lay above 3, rather than to one side of it; Figure 2 shows this arrangement. The whole path of the light along these mirrors was enclosed and covered, to lessen the effect of air currents and other local disturbances. An acetylene flame was carried as a source of light. A telescope magnifying thirty-five diameters gave distinct vision of mirror 8, at whose surface the interference fringes are apparently localized.



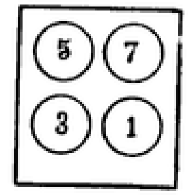


Fig. 1 Fig. 2

The mirrors, being silvered and polished, were put in place, and the lengths of the two paths were measured with a split rod and then made nearly equal. Establishing interferences in sodium light, we found the central part of a series of some seven hundred interferences which are brighter than the adjoining three hundred. With no long search, we could see interferences in white light, although we had provided no screw for moving a mirror with its surface always parallel to a given surface. This we had avoided, in order to have everything about the two arms as symmetrical as possible.

We now computed the direction and velocity of the motion of the centre of the apparatus by compounding the annual motion in the orbit of the earth with the motion of the solar system towards a certain point in the heavens. During part of August, the whole of September, and nearly all of October, this motion never coincides with the plane of our apparatus. For other dates, there are two hours in each day when the motion is in the desired plane, except for two days when the two hours coalesce into one. At the beginning of June the two hours are about 11h. 20m. A.M., mean solar time, and 9h. 50m. P.M. At the time of our last set of observations, July 5th to July 9th, the hours were 11h. 40M. A.M. and 8h. 20m. P.M., local mean time.

After many trials, with filar micrometer, and with scale on mirror 8, we found it advisable to accumulate a great number of observations made as rapidly as might be. What we had to do, in presence of all the local disturbances of density of the air which sometimes made observation impossible and always made it difficult, was as if we were trying to measure the solar atmospheric tide. If we could vary the period of this tide at will by controlling the revolutions of the earth, we should doubtless get a result sooner by accelerating the latter and making a great number of observations in a given time, rather than by retarding the period in order to measure with very great precision the hourly height of a barometer. We therefore proceeded as follows. One observer walked around with the moving apparatus, his eye at the telescope, while he maintained the rotation by an occasional gentle pull on a cord so fixed as not to bring any strain to bear on the cross arms of the apparatus. The room was darkened. The other observer also went around with the apparatus; as an index showed the azimuth of the apparatus to be that indicated by one of sixteen equidistant marks, he called out the number or some other signal. The first observer replied with the reading for the given azimuth, which the second observer recorded. The next azimuth was called at the proper instant, the reading given, and so on. Half the time, perhaps, the observations were interrupted before they became numerous enough to be useful, being stopped by excessive displacement of fringes owing to temperature changes and the like. But patience is a possession without which no one is likely to begin observations of this kind. Runs of twenty and thirty turns, involving 320 or 480 readings, were not uncommon. A run of thirty turns meant that the observer, who could sometimes make a turn of sixteen

readings in sixty-five or seventy-five seconds, walked half a mile while making the severe effort involved in keeping his eye at the moving eyepiece without the least interruption for half an hour. The work is, of course, somewhat exhausting.

Observation with this apparatus could not begin till the month of August, and we had to stop without having accomplished as much as was desirable. During the busy season of the school year, observation is impossible. We had therefore expected to resume our work in June. But we then found that our pine apparatus had so much suffered from the dryness of the building that we could not maintain the adjustment of our fringes. We could not, in the time, build another apparatus of timber which had not been dried all winter, nor was it thought well to construct another apparatus closely resembling the first. While planning a new apparatus, we made a couple of experiments to show, what was well enough known, that difference of magnetic attraction on the iron parts of our apparatus could not disturb our observations. We suspended two massive pieces of iron at the ends of one arm, so that one should be in the lines of magnetic force of the earth's field, and the other transverse to them, these relations being reversed on reversing the position of the apparatus. But observations with this load of iron gave the same result as before. Next we placed an analytical balance on one arm, with which to weigh a bur of iron at the extremity of that arm. It was so placed that at one azimuth the bar was nearly in the lines of force, and at another was transverse to them. If there were a difference of half a milligram in twelve hundred grams, it would have been detected, but no such difference existed. We found by trial how much a weight of a hundred grams displaced our fringes, and so learned, as was known before, that the influence of the earth's magnetism could not be a disturbing factor.

The Rumford Committee of the American Academy of Arts and Sciences having made a grant in aid of this experiment, we carried out our original plan of making a steel structure so rigid as to permit easy and satisfactory observation. In this new apparatus all the optical parts are carried by a steel frame built of plate and angle-iron, somewhat like a bridge girder. A cubical steel box, fourteen inches on each edge, constitutes the centre of the structure, which is in the form of a cross. To each of the four sides of this cube are firmly attached arms, each about six feet and a half in length. Each arm is made of steel plates, three eighths of an inch thick, eighteen inches wide at one end, and six inches wide at the other, standing on edge, and kept fourteen inches apart by suitable plates, angle-irons, and other braces; thus are formed hollow beams of great rigidity, especially in a vertical direction. This framework is shown in Plate 1, from which it is seen that the structure is in effect two rigid beams, each fourteen feet long, crossing at right angles, and symmetrical as regards strength and rigidity.

On two ends of the cross, S and T, Figure 1, are two upright cast-iron frames, fastened by bolts, each of which carries four mirrors, marked 2, 4, 6, and 8. Against the corners of each of these frames rest four pine rods, three quarters of an inch in diameter and fourteen feet long. Each rod is supported throughout its length by a brass tube an inch in diameter; each pair of tubes is joined together in a vertical truss, as shown in Plate 1. Against the farther end of these rods there rest the frames which hold the two sets of mirrors, I and II, Figure 1. Each of the latter frames is freely suspended by two thin steel ribbons and is held firmly against the pine rods, and through these against one of the two fixed mirror holders; the pressure is applied by means of adjustable spiral springs. Thus the distance between tho opposite systems of mirrors depends upon the pine rods only. This construction permits the convenient substitution of distance rods of other material, so that experiments might be easily made to test the theory that the dimensions of different materials are differently affected by motion of translation through the ether. The diagonal mirrors are carried by adjustable supports bolted to the steel frame near its centre.

The observing telescope of an inch and a half aperture with a magnifying power of thirty-five is attached to a support bolted to the steel frame. The acetylene lamp and the four-inch condensing lens stand on a wooden shelf as far as convenient from the mirrors, which are protected by asbestos screens with air spaces. The whole path of light through the apparatus is enclosed by a wooden cover made of pine seven eighths of an inch thick, having doors and glass windows where these are required. The observer's eyes are protected from extraneous light by a dark cloth.

The entire apparatus, weighing about nineteen hundred pounds, rests upon a circular wooden platform about five feet in diameter. An annular projection on the under side of the platform is immersed in mercury of such depth as to float the platform and the apparatus. The mercury is contained in an annular

cast-iron trough of such dimensions as to leave a clearance of about half an inch between the iron and the wooden float. A small pin at the centre of the iron trough enters a socket in the wooden float, so as to keep the float from touching the sides of the trough.

Plate 1 shows the steel framework and float, together with the trusses which are to support the distance pieces. The mirror frames and the telescope are in position, but lamp and lens are not in position. Plate 2 shows the apparatus as it appeared at the time of the observations.

With this apparatus, fringes adjusted on a certain Monday remained in adjustment throughout the whole of the week during which our observations continued. Observations were made in precisely the same manner as with the previous apparatus.

We obtained 260 complete observations, consisting each of readings at sixteen azimuths around a circumference. At the date of the observations, the annual motion of the earth, together with the motion of the solar system, may be taken as 33.5 kilometers a second. It is assumed that the solar system is moving towards a point whose right ascension is 277.5°, and whose north declination is 35°, with a velocity of eleven miles a second. The velocity of light being 300,000 kilometers a second, the ratio of the squares of the velocities is 0.72×10^8. The length of path of a ray in our apparatus was 3224 centimeters, in which distance there are contained 5.5×10^7 wave lengths of sodium light. The expected effect being doubled by rotation through 90, the displacement of fringes expected on the simple kinematic theory will be $11 \times 10^7 \div 0.72 \times 10^8$. This is 1.5 wave length.

As was indicated, there were two times in the day when observation was advisable. The direction of the motion with reference to a fixed line on the floor of the room being computed for the two hours, we were able to superimpose those observations which coincided with the line of drift for the two hours of observation. Doing this, and subtracting a constant so as to make the algebraic sum of the observations equal to zero, we get a certain result. Then adding the first term to the ninth, and so on, since the effect repeats itself in a circumference, we get our final result, as follows: —

Result of observations at various azimuths.

Azimuths	8	7	6	5	4	3	2	1
Wave lengths	+0.0075	+0.0088	+0.0113	-0.0102	-0.0123	+0.0027	-0.0021	-0.0062

Azimuth mark 1 denotes that the telescope of the apparatus was directed N. 29° E.; 3, N. 16° W.; 5, N. 61° W., &c.

These numbers may be confidently pronounced to be due to errors of observation. We computed from them several curves of the theoretical form, having their origin at sixteen equidistant points in the half circumference; this was done by the method of least squares. The most probable of these curves had an amplitude of 0.0073 wave lengths, and its zero was half-way between the azimuths marked 4 and 5. The average of the given observations is 0.0076 wave lengths; after subtracting the ordinates of the computed curve, the mean residual was 0.0066 wave lengths. The sum of the squares of the residuals before was 565×10^{-4}; afterwards, it was 329×10^{-4}.

We may therefore declare that the experiment shows that if there is any effect of the nature expected, it is not more than the hundredth part of the computed value. If pine is affected at all, as has been suggested, it is affected to the same amount as is sandstone. If the ether near the apparatus did not move with it, the difference in velocity was less than 3.5 kilometers a second, unless the effect on the materials annulled the effect sought

Some have thought that the former experiment only proved that the ether *in a certain basement room* was carried along with it. We desire to place the apparatus on a hill, covered only with a transparent covering, to see if any effect could be there detected. As the Rumford Committee have allowed us thus to utilize an unexpended balance, we hope to make the experiment in this form, should it be possible to make observations in trying conditions.

1. On the Relative Motion of the Earth and the Luminiferous Ether. A. A. Michelson and E. W. Morley. Am. Jour. Sci., 34, 333.